FPGA-Based RONJA Twister

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Abstract

RONJA is an open-source device which utilizes a visible-light beam for establishing a wireless point-to-point data link. It is designed to operate in 10Mbps full-duplex mode over a distance up to 1.4 km. This paper deals with one of RONJA modules referred to as RONJA Twister. The module forms an interface between metallic Ethernet and the actual optical transmission. Our goal was to reimplement this module using FPGA technology in a backward-compatible manner. Furthermore, we have proposed and implemented notable extensions to the original device in order to mitigate several issues of the earlier implementation. A fully functional prototype which can be used as a drop-in replacement for the original Twister module was created. In contrast to the original device, it comprises a fully stateful implementation of Ethernet physical layer (PHY) including Auto-Negotiation support. The proposed extensions considerably simplify RONJA device deployment in present-day Ethernet networks.

Categories and Subject Descriptors

B.4 [**Input/output and Data Communications**]: Data Communications Devices

Keywords

Free-space optics, RONJA, Twister, Ethernet, IEEE 802.3, Auto-Negotiation, FPGA, VHDL

1. Introduction

RONJA [1] is a hardware project whose product is a wireless networking device of the same name, based on data transmission via a modulated light beam sent through the atmosphere. The project is unique not only because of the unconventional way of data transmission but also due to its open-source nature. This article focuses on one of RONJA device modules named RONJA Twister.

The purpose of RONJA Twister module [2] is to transform the signal between a standard metallic segment of Ethernet 10Base-T and the optical transmission itself. Since the transmission via modulated light beam is not fully compatible with Ethernet specification, the transformation involves altering the signal in such way that is suitable for the optical channel. In addition, Twister has to ensure proper Ethernet PHY signalling (e.g. generation of Normal Link Pulses that indicate link activity).

2. Original RONJA Twister

The RONJA project already implements the Twister module. This module is built using off-the-shelf logic gates in discrete packages, without the use of programmable arrays or processors. Being stateless, the device does not take the current link mode into consideration and neither does adjust its behaviour with respect to the Ethernet link state. Another drawback of the original Twister implementation is its inability to propagate supported link modes to other devices on the link segment.

The idea of implementing the module using common off-the-shelf logic gates was motivated by general availability of those components and by simpler device construction. However, the stateless Ethernet PHY implementation prevents an automatic configuration of the network segment. Another major issue is a limited half-duplex operation for those devices that do not allow to set the link properties manually. In such situations, the danger of *duplex mismatch*[1] arises.

3. Proposed solution

The issues mentioned previously could be prevented by implementing Auto-Negotiation support for the Twister module. Despite being an optional Ethernet PHY feature, Auto-Negotiation is (according to the standard [3]) a preferred way to configure the network segment mode. Furthermore, the Auto-Negotiation protocol is in many cases the only means for link mode configuration since many Ethernet switches do not support manual link setup.

Auto-Negotiation is a mechanism that allows a pair of Ethernet devices to interchange the information about

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[1] The term *duplex mismatch* refers to a misconfigruration when a pair of devices sharing a single link segment is wrongly configured to operate in different duplex modes. This results in a very limited segment throughput.

their available modes of operation and to choose the highest mutually supported option. The information about device's supported modes is represented by a 16-bit *link code word* and physically transmitted using so called *fast link pulses* (FLP).

As the Auto-Negotiation phase is performed exclusively during the Ethernet link establishment, it was necessary to redesign the original stateless PHY implementation. As a result, a fully stateful Ethernet PHY was added to the Twister module. The proposed PHY implementation is fully aware of the link state and mode is able to react to a link loss or link reestablishment. If necessary, the module may also perform link mode renegotiation.

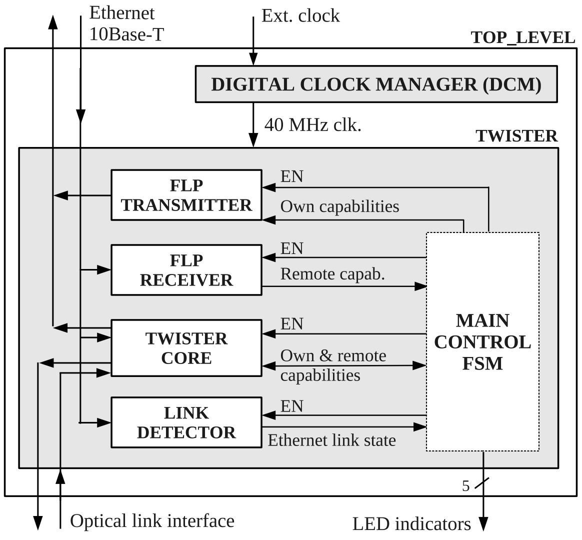

Figure 1: Implemented system structure

4. The structure of the system

The extended Twister consists of a hierarchical strucure of components that together implement Ethernet PHY, Auto-Negotiation protocol and the signal transformation as required for the optical transmission. Figure 1 presents a block-level schematic of the proposed system.

The purpose of the `FLP transmitter` component is to generate fast link pulses carrying information about Twister's supported link modes. Conversely, `FLP receiver` detects and decodes FLP pulses sent by the Ethernet link partner. The Ethernet link state is monitored by the `Link detector` component. The `Twister Core` component transforms the data signal as required for the optical transmission. The whole system is coordinated by a FSM contained within the `twister` component.

5. Results

With respect to the problem being solved, the FPGA technology was chosen as the implementation platform. Xilinx Spartan-3AN XC3S50AN FPGA chip, which consists of of 704 slices was used. The proposed architecture was described in VHDL, simulated using ModelSIM and synthesized using Xilinx ISE 13.1. Results of the synthesis are summarized in table 5. The whole system occupies approximately 30 % of the FPGA chip resources.

The functionality of the system was successfully tested using FITkit [4] development kit. In addition, a standalone and autonomous Twister prototype was created.

FPGA resource	Occupied	Total	Usage
Slice flip-flops	207	1408	14 %
4-input LUTs	343	1408	24 %
"Slice" units	217	704	30 %
Bonded IOs	20	108	18 %
Global clock nets	6	24	25 %
DCM units	1	2	50 %

Table 1: XC3S50AN occupied resources

6. Discussion

The complete redesign of Ethernet PHY in the Twister module and additional Auto-Negotiation support prevents the issues of the original Twister implementation outlined in the section 2. These enhancements also make the integration of RONJA devices in Ethernet networks considerably simpler.

The implementation of a relatively complex Auto-Negotiation protocol would not have been feasible without the use of any form of programmable logic devices. Moreover, the introduction of the FPGA technology allowed to reduce the PCB size by 45 %.

The significant reduction of PCB dimensions allows to physically integrate RONJA Twister and the optical transmitter module and thus make the construction of the whole RONJA device less complex. The flexibility of the device could be further improved in the future by implementing the Power over Ethernet (PoE) standard.

The cost of the components required for the extended Twister module is comparable to the expenses for the original module designed using discrete logic IOs. In case of mass production, it is expected that the unit cost for manufacturing the extended Twister device would be significantly lower since both the number of components and the PCB size were substantially reduced.

7. Conclusions

In this article, a FPGA-based RONJA Twister module was proposed. From the perspective of future enhancements, the application of FPGA technology allows a great degree of flexibility. The system currently occupies approximately 30 % of the available FPGA chip resources. Therefore, a sufficient capacity exists for future extensions of the Twister module. For example, it is possible to implement some advanced modulation technique in order to increase bandwidth, reliability or range.

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